



# Producibility Aspects of Composite Material Qualification and Certification



**Presented at**  
**AEROMAT**  
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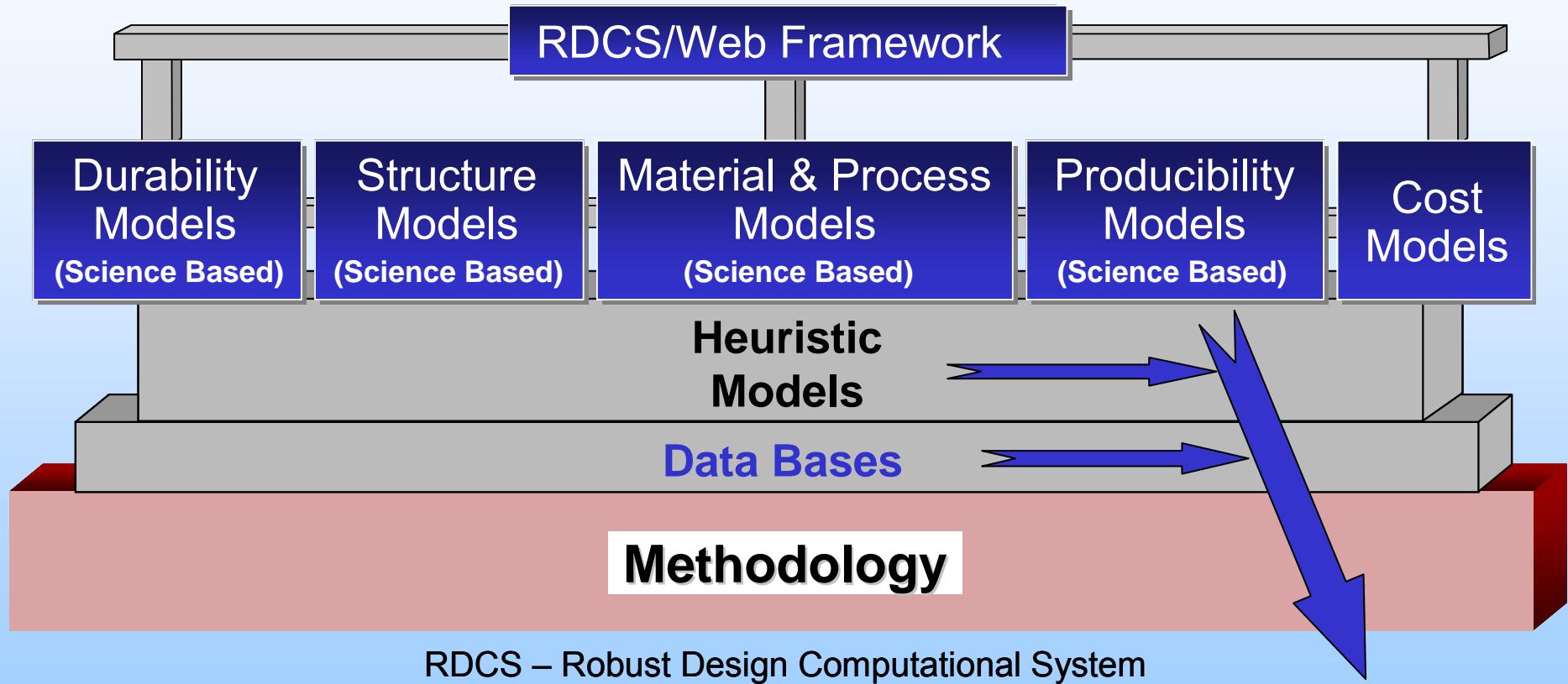
**Jointly accomplished by BOEING Led Team and the U.S. Government  
under the guidance of NAST (TIA N00421-01-3-0098)**

*This program was developed under the guidance of Dr. Steve Wax and Dr. Leo Christodoulou of DARPA. It is under the technical direction of Dr. Ray Meilunas of NAVAIR.*

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# Overall Program Concept

The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products



**Module:** linked set of related models/databases; 8 in AIM-C Phase I Program - Resin, Fiber, Prepreg, Processing, Lamina, Structures, Durability, and **Producibility**



# Producibility Module Definitions

## Definition:

**A Controller Module to Compare Requirements to Manufacturing Capabilities For Quality Components**

## Corollaries:

- **Can I Make It?**
- **With What Degree of Success?**
- **How Can I Make It?**
- **By Which Manufacturing Sequence Should It Be Made?**

- The Initial Envisioned Module Provides Heuristics Which Give Guidance Through Part Thermal Processing (Cure/Post Cure)
- Higher Level Module That Manages And Guides The Other Modules To Exercise Only The Tools That Are Necessary To Address The Designers Requirements
- Phase 1 Program Only Looking At Autoclave Processing



# Producibility Module Definitions

## Additional Definitions:

### ➤ Manufacturing Capabilities

- Ability to Fabricate the Unassembled Components with Identified Materials and Manufacturing Methods

### ➤ Quality Requirements/Parameters

- Meets Functional Requirements (Strength, Stiffness, Dimensions, Etc.)
- Requirements/Parameters are Identifiable, Measurable, and Boundable

### ➤ Manufacturing/Processing Steps/Areas

- Ply Cutting
- Layup
- Debulking
- Bagging
- Equipment
- Tooling
- Repairability

### ➤ Component Quality Requirements/Parameters

- Dimensions
- Voids
- Porosity
- Inclusions
- Surface Waviness
- Fiber Volume/Resin Content
- In-Plane & Out of Plane Fiber Distortion
- Surface Finish

### ➤ In-Process Quality Requirements/Parameters

- Ply Angle
- Ply Lap/Gap
- Out Time
- Freezer Time
- Equipment Certifications
- Heat-up Rates
- Cure Time, Temp, Pressure
- Abort Conditions
- Debulk Time, Temp, Pressure

# Module Functional Flow Chart

## Design User Requirements

- Kind of Structure (Skins, Substructure, Doors, Etc.)
- Class of Structure (Primary, Secondary, etc.)
- Type of Structure (Monolithic, Cocure, Etc.)
- Configuration/Features
- Tolerances
- Fiber/Fiber Form
- Fiber Volume/ Resin Content
- Quality (Voids, etc.)
- Additional Mat'l's
- Secondary Operations
- Repairability
- Manufacturing Methods

CAD Master Data Tie

## Modules/RDCS

- Resin
- Fiber
- Prepreg
- Processing
- Lamina
- Structure
- Durability

## Variability/Error Analysis Results

## Key Mat'l & Process Controls

## Producibility Module

## Methodology (Divergence/Risk)

## Knowledge Bases

- Lessons Learned
- Structure Kind, Type..
- Configuration
- Parts
- Secondary Operations
- Repairability
- Sourcing Capabilities/ Capacities
- Equipment
- Tooling
- Quality
- Test Methods

## CACC

## CAICAT, ATMCS, FiberSim, Panform

## Outputs

## Other User Requirements

## Certification User Requirements

- Changed Mat'l, Process, Equipment, Tooling

- Divergence/Risk for Requirements Relative to Capabilities
- Risk Reduction Recommendations
- Costs/Times
- Design/Manufacturing Recommendations
- Mat'l & Process Spec Recommendations
- Quality Plan/Recommendations
- Indirect Materials
- Tooling Definitions/Concepts



## Productivity Module Software

*Most aspects of producibility are very subjective and/or based on previous experience with very little existing software. Therefore, it is proposed to use existing software capable of logical programming along with data bases that will contain pertinent information to be interrogated through SQL.*

- **Heuristic and/or Rule Based Software  
(Java, Visual Basic, C++....)**
- **Knowledge/Data Bases  
(Access, Oracle, M-Vision,...)**
- **Science Based Objective Models  
(Fortran, C++, etc.)**
  - **CACC** (Thickness, Voids/Porosity, Resin Flow Bagging, Debulking, Tooling, etc.)



# Knowledge/Data Bases

## Manufacturing/Processing Steps

- Cutting
- Layup
- Debulking
- Cure
- NDE/Quality
- Testing

## Equipment

- Cutting
- Collation
- Ovens
- Autoclaves
- NDE
- Testing

## Lessons Learned

- Configuration/Type/ Class (Parts)
- Methodology
- Material(s) and Material Combinations
- Manufacturing/ Processing Steps
- Tooling
- Equipment
- Quality (In-process and Final Part)
- Testing/Evaluations
- Secondary Operations
- Repair
- RDT&E Costs/Times?

## Tooling

- Primary Tooling
- Secondary Tooling

## Secondary Operations

- Bonding
- Painting
- Coating

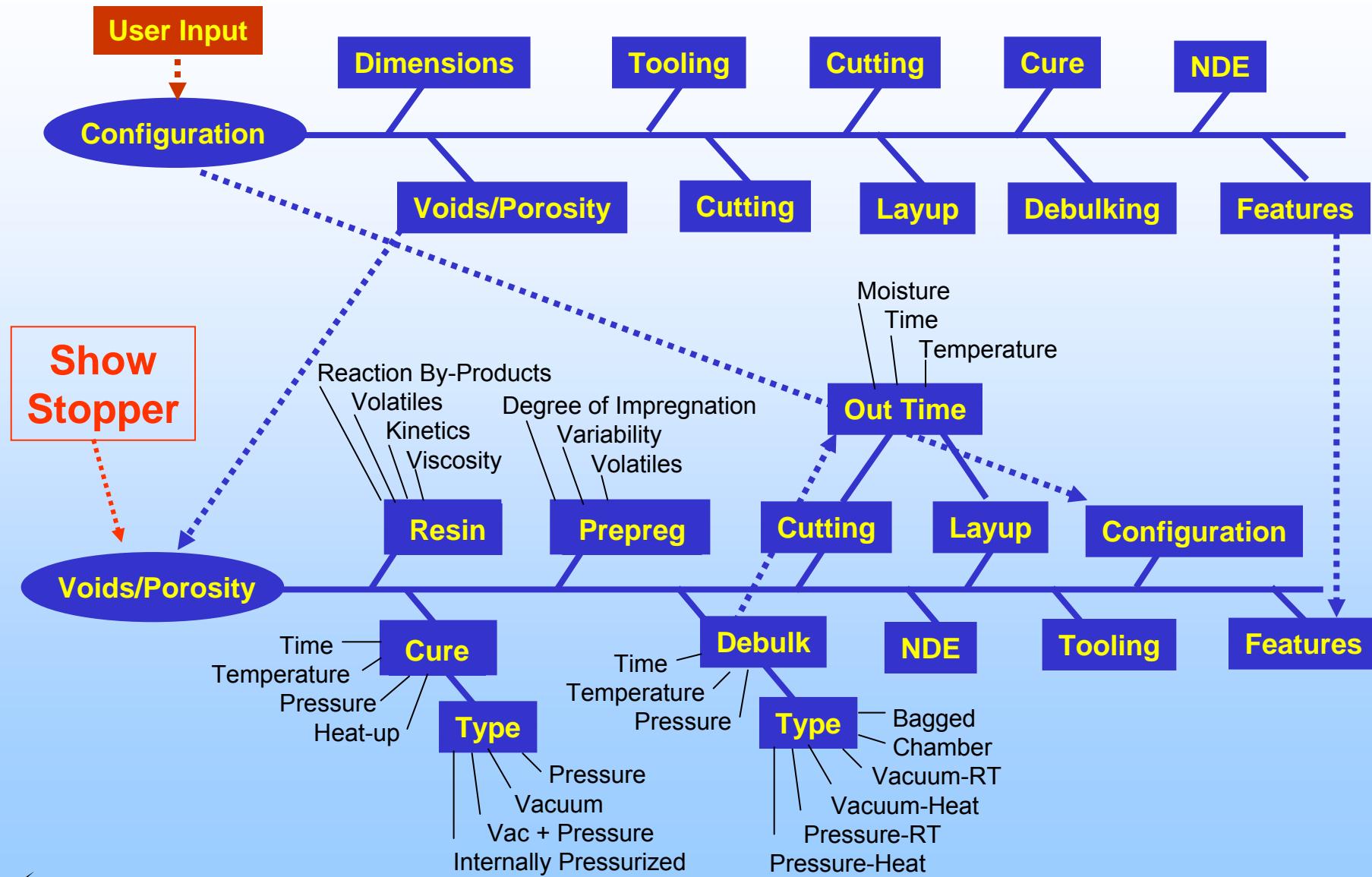
## Repair

- In-process
- Final Part (After Cure)
- Material Compatibility

## Other

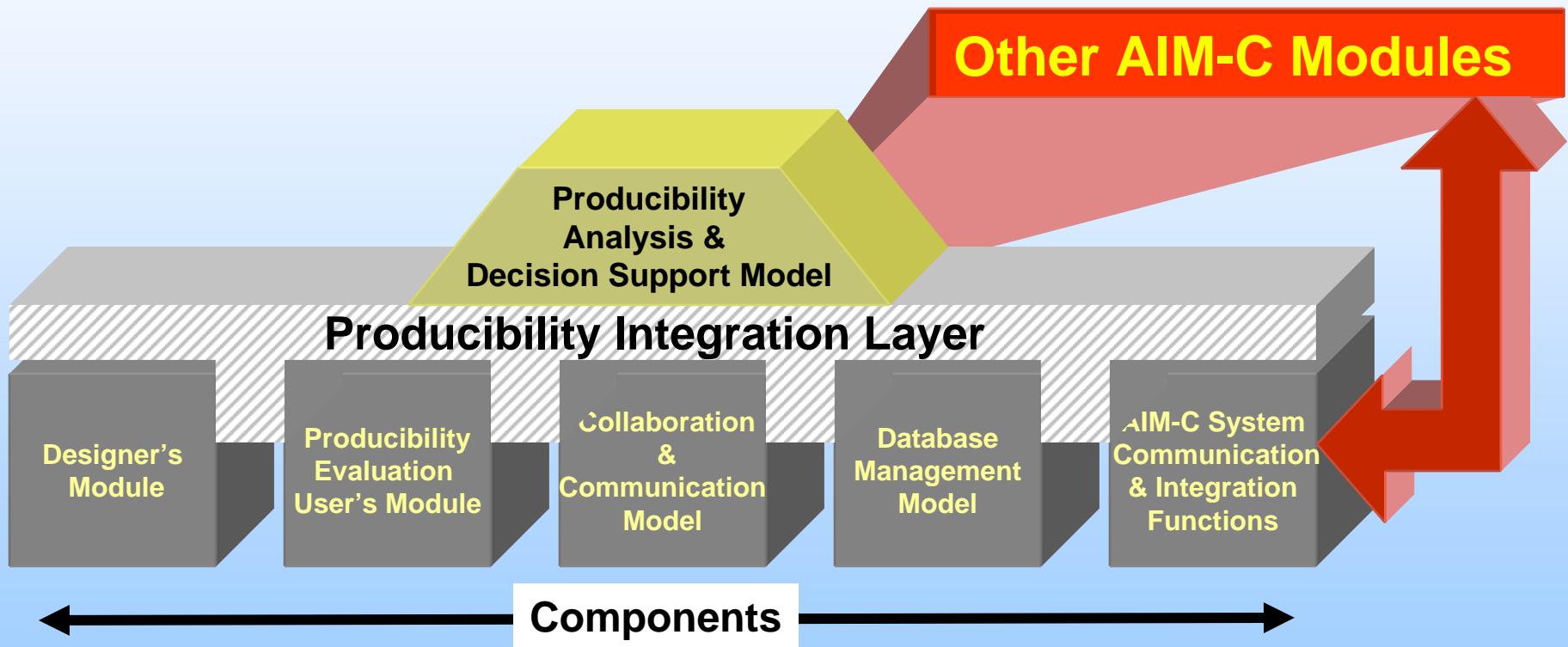
- Health & Safety
- ITAR
- Proprietary Info

# Cause and Effect Diagrams



# AIM-C Producibility Module

*Producibility Module Has Integrated Components That In Turn.....*

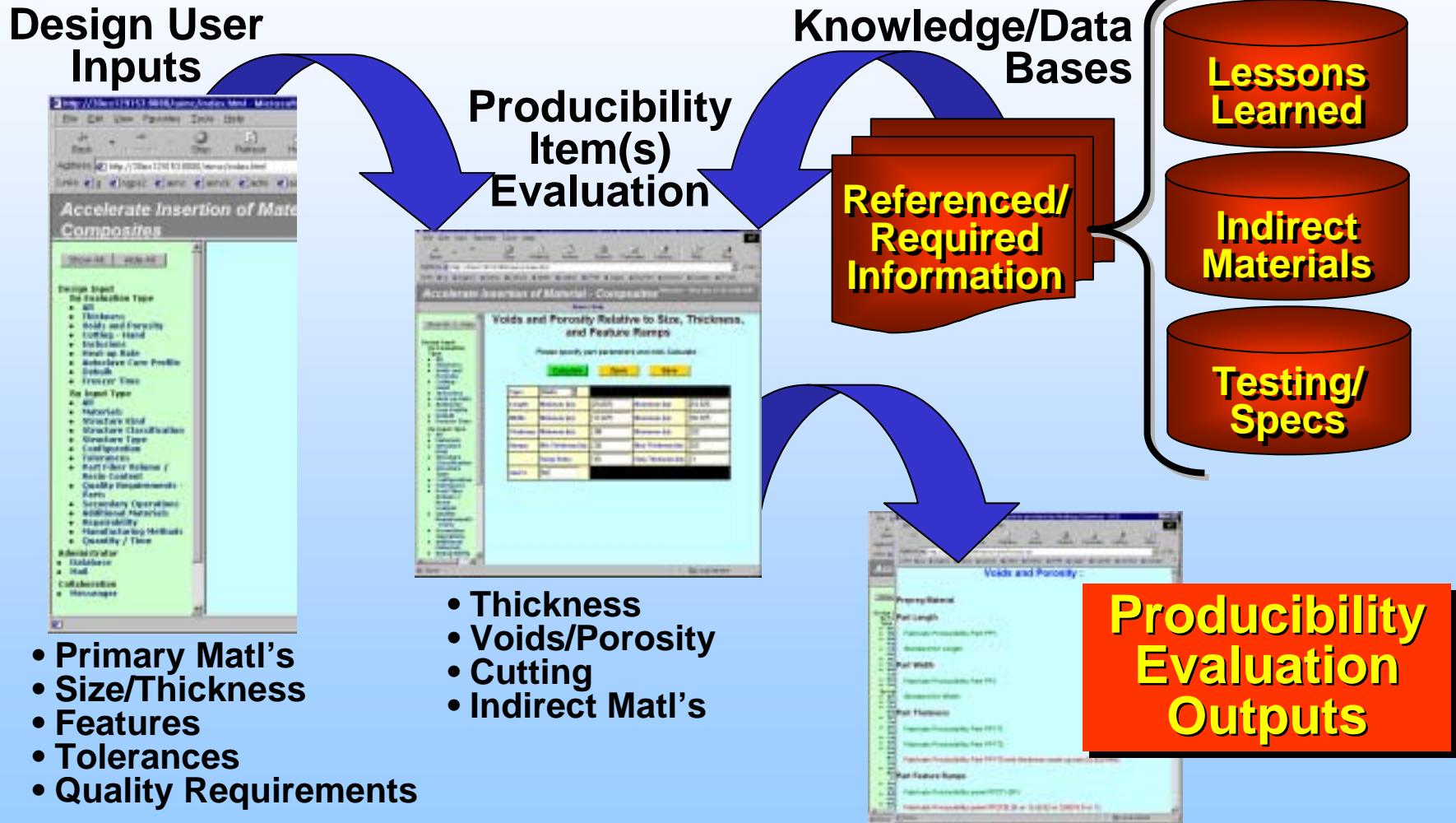


*.....Are Integrated With Other AIM-C Modules*



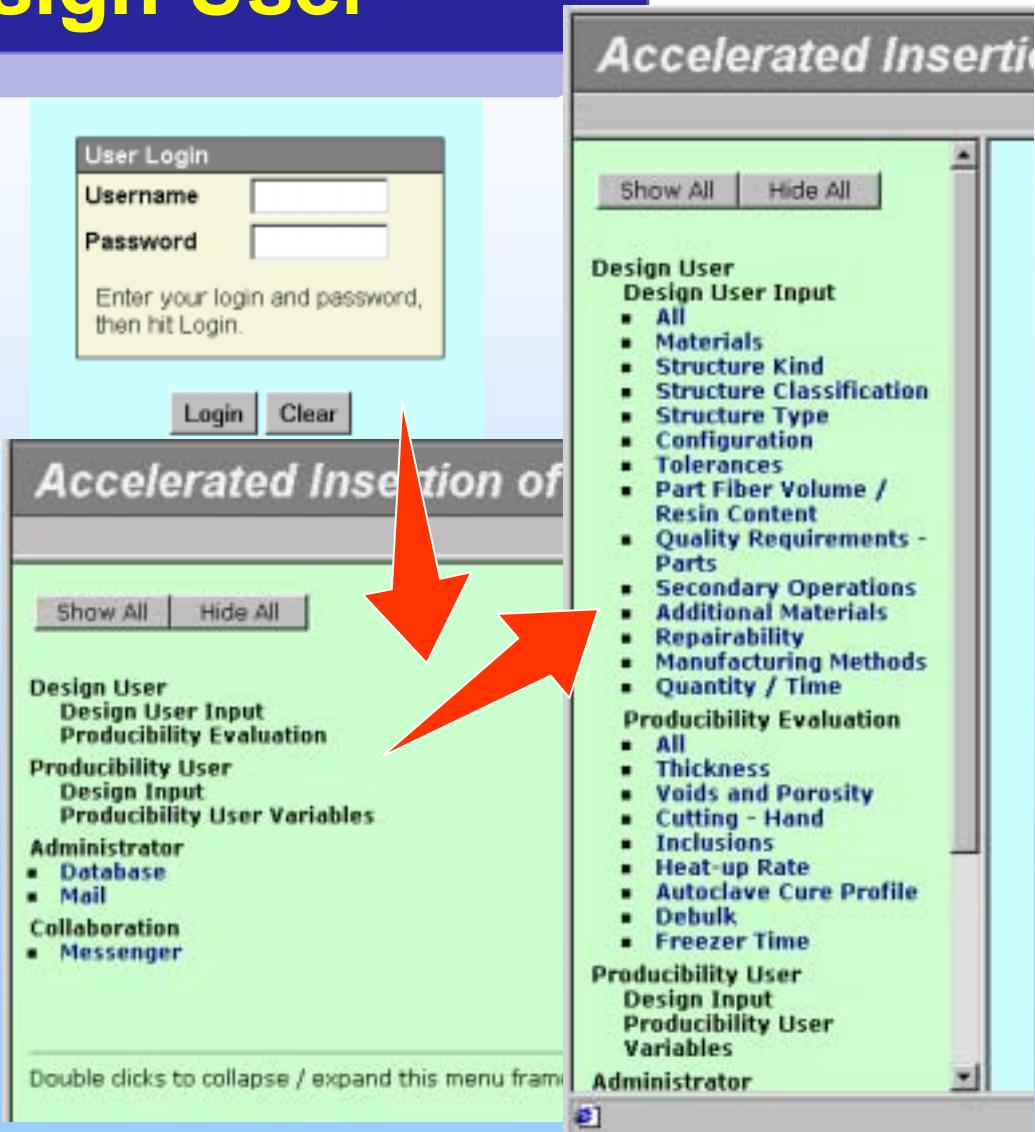
# Productivity Module

## Demo Overview



# Starting Module Design User

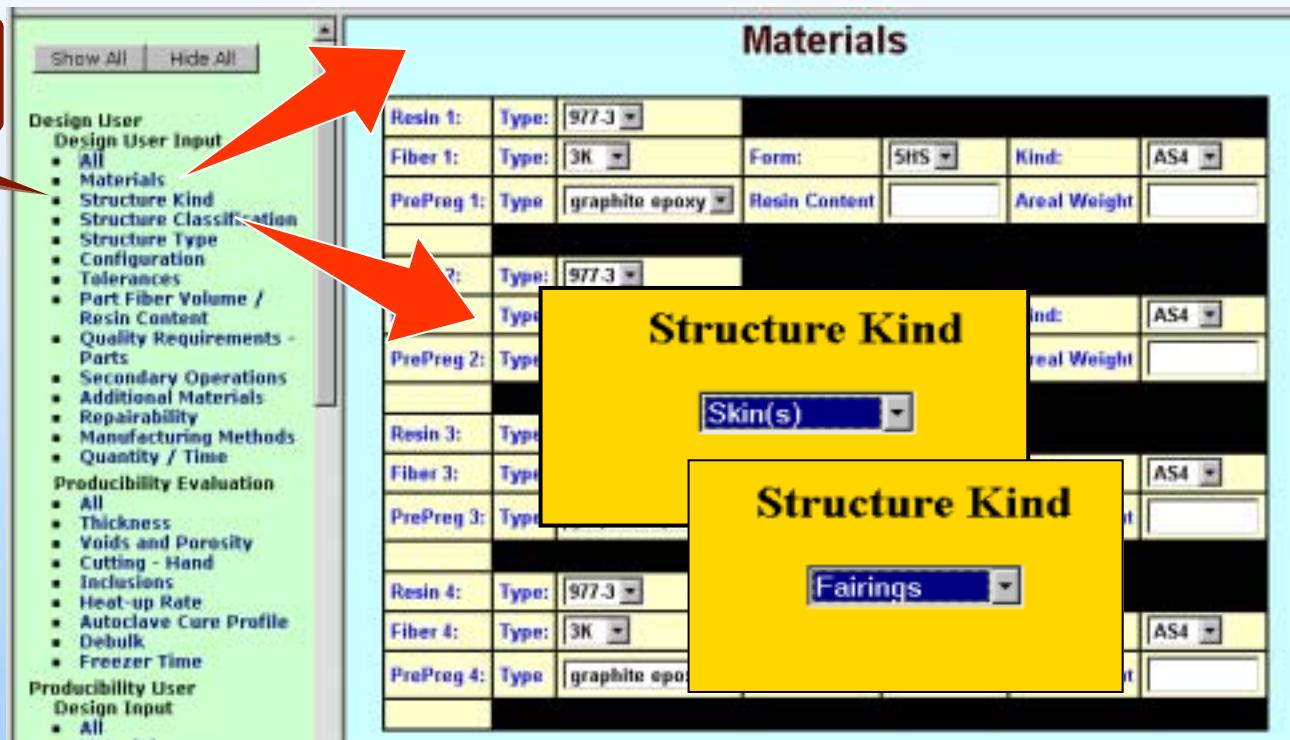
- Control of Users
- Multiple User Types
- Administration Control for Data Bases
- Design User Variables for Producibility
- Producibility Evaluations From a Design User Standpoint
- Producibility Evaluations From a Producibility User Standpoint



# Design User Inputs

## Design User Definable Variables

- Design User Sets Problem/Requirements For Producibility Evaluations
- Ties to Other Design User Items
- Allows Individual Producibility Item Evaluations or All Items



*Producibility Evaluations/Outputs  
According to User Inputs/Requirements*



# Producibility – Quality Thickness

Show All | Hide All

**Design User**

- Design User Input
  - All
  - Materials
  - Structure Kind
  - Structure Classification
  - Structure Type
  - Configuration
  - Tolerances
  - Part Fiber Volume / Resin Content
  - Quality Requirements - Parts
  - Secondary Operations
  - Additional Materials
  - Repairability
  - Manufacturing Methods
  - Quantity / Time
- Producibility Evaluation
  - All
  - Thickness**
  - Voids and Porosity
  - Cutting - Hand
  - Inclusions
  - Heat-up Rate
  - Autoclave Cure Profile
  - Debulk
  - Freezer Time
- Producibility User

Design Input

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type

**Thickness for Producibility Evaluation**

Please specify part parameters and click Calculate :

Calculate Open Save

**Tolerance Requirements**

Prepreg Thickness:			
Part Thickness:	Min:	Max:	
Tolerance Values	Nom:	Min:	Max:



**Ties to Resin,  
Fiber, and  
Prepreg  
Modules**

# Producibility – Quality: Thickness

## Thickness for Producibility Evaluation

	Avg	Min	Max
Number of Piles	N/A	25	78
Per Ply Thickness	0	0	0
Min Part Thickness	0	0	0
Max Part Thickness	0	0	0

Problem: min part thickness is 0

Problem: max part thickness is 0

[View Test Method](#)

## Testing

### TEST METHOD

Specification	MIL-PRF-46190A
Specimen Size	12x12
No. of Spec.	5



**Multiple Output Options and Information**

## Specifications

**Identification of Potential Problems**

SEARCH-00009  
MIL-PRF-46190A  
23 SEP 1997  
0010000000  
MIL-P-46190  
18 September 1990

PERFORMANCE SPECIFICATION  
PRF46190. WOVEN FABRIC, CARBON FIBER, RESIN IMPREGNATED

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 **Scope.** This specification establishes the requirements for resin impregnated, high strength, carbon fiber, woven fabric prepreg (see 6.1).

1.2 **Classification.** Prepreg is to be of the class specified (see 6.2):

Class A - TOW Mechanical properties

Ultimate tensile strength = 549 thousand pounds per

# Producibility – Quality: Voids

Show All | Hide All

Design User

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements
- Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

Producibility Evaluation

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Producibility User

Design Input

- All

## Voids and Porosity Relative to Size, Thickness, and Feature Ramps

Please specify part parameters and click Calculate :

Calculate   Open   Save

Prepreg:	Resin Type	977-3	
	Fiber Type	3K	
	Prepreg Type	graphite epoxy	
Length:	Minimum (in):		Maximum (in):
Width:	Minimum (in):		Maximum (in):
Thickness:	Minimum (in):		Maximum (in):
Ramps:	Min Thickness (in):		Max Thickness (in):
	Ramp Ratio:		Step Thickness (in):
Max. Void %			



# Producibility – Quality: Voids

## Voids and Porosity :

Prepreg Material

Part Length

[Fabricate Producibility Part PP1 \(view\)](#)

Standard for Length

Part Width

[Fabricate Producibility Part PP1 \(view\)](#)

Standard for W

Part Thickness

[Fabricate Producibility Part PP1T1 \(view\) and Thin test panel \[0.0\] inches thick.](#)

[Fabricate Producibility Part PP1T2 \(view\)](#)

[Fabricate Producibility Part PP1T3 \(view\) and thickness scale-up part \[0.0\] thick.](#)

Part Feature Ramps

[Fabricate Producibility panel PP2T1-2Rt \(view\)](#)

[Fabricate Producibility panel PP2T\(0.0 or 1\)-\(0.0 or 2\)R\(0.0 or 1\) \(view\)](#)

Part Quantity - Voids

NDE Standards (Effect of Defect)

[Fabricate NDE standard part PP\\_NDE2 \(view\) with \[0.0 %\] voids.](#)

[Fabricate NDE standard part PP\\_NDE2 \(view\) with 2X\[0.0 %\] voids.](#)

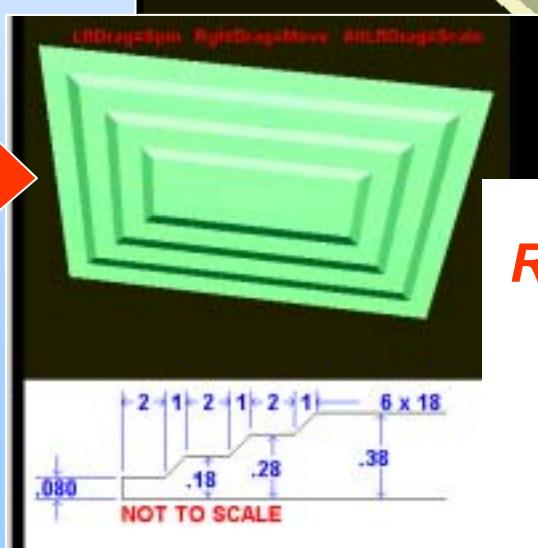
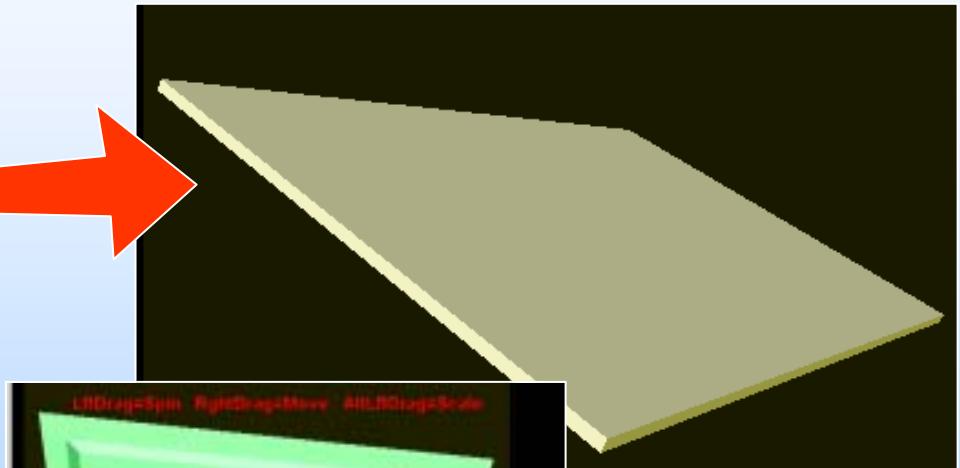
[Fabricate NDE standard part PP\\_NDE2 \(view\) with 3X\[0.0 %\] voids.](#)

Mechanical Property Panels (Effect of Defect)

[Fabricate Compression test Panel\(s\) CTP1 \(view\) with \[0.0 %\] voids.](#)

[Fabricate Compression test Panel\(s\) CTP1 \(view\) with 2X\[0.0 %\] voids.](#)

[Fabricate Compression test Panel\(s\) CTP1 \(view\) with 3X\[0.0 %\] voids.](#)



**Output  
Recommendations  
Based on User  
Inputs, Std  
Produce Tests,  
and Lessons  
Learned**

# Producibility – Method: Cutting

Producibility User Design Input

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements
  - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

Producibility User Variables

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Administrator Collaboration

**Cutting - Hand**

Please specify Product Name and click Calculate :

Calculate   Open   Save

Resin:	Type:	977-3	Film:	SHS	Kind:	AS4
Fiber:	Type:	3K	Backing Paper:	Product A		
Separator Material:	Product Name:	Product A				
Spool Requirements:	Facility:	Boeing	Weight(lbs):	10	Diameter(inches):	5
Resin Environment Requirements:	Storage greater than 5°					
Part Quality:	Inclusions:	Cutting				
In-process Quality:	Angle Accuracy:	Facility:	Boeing	Cutting Angle Accuracy:	overall average	

**Methods Take Into Account Facilities/Capabilities, Direct Materials, Indirect Materials, Part Quality, In-Process Quality, and Interactions With Other Items**



# Producibility – Method: Cutting

## Results for Cutting - Hand

### Prepreg Material - Indirect Materials

#### Backing Paper

Product A associated with Prepreg

Evaluate prepreg backing paper per??? Specification for NDE detectability and contamination.

Product A associated with NDE Compatibility

Evaluate prepreg backing paper per??? Specification for contamination.

#### Separator Material

Evaluate prepreg separator per??? Specification for prepreg usage.

Product A associated with ResinID 1

Product A associated with NDE Compatibility

Evaluate prepreg separator per??? Specification for prepreg usage, NDE detectability, and contamination.

### Prepreg Material - Spool Requirements

#### Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs investigation.

#### Resin Environment Requirements

### Prepreg Material - Spool Requirements

#### Cutting Capability

There is a conflict between cutting capabilities and prepreg spool ???, Needs investigation.

#### Resin Environment Requirements

TBD.

### Part Quality - Inclusion

#### Indirect Materials - Cutting

Product A associated with Cutting

Evaluate cutting separator per??? Specification for prepreg usage.

Product A associated with NDE Compatibility

Evaluate cutting separator per??? Specification for prepreg usage, NDE detectability, and contamination.

### In-process Quality - Angle Accuracy

Angle accuracy capability (total layup angle accuracy/repeatability) can not meet quality requirements of [angle accuracy] because cutting accuracy/repeatability is ?? And layup accuracy/repeatability is ??.

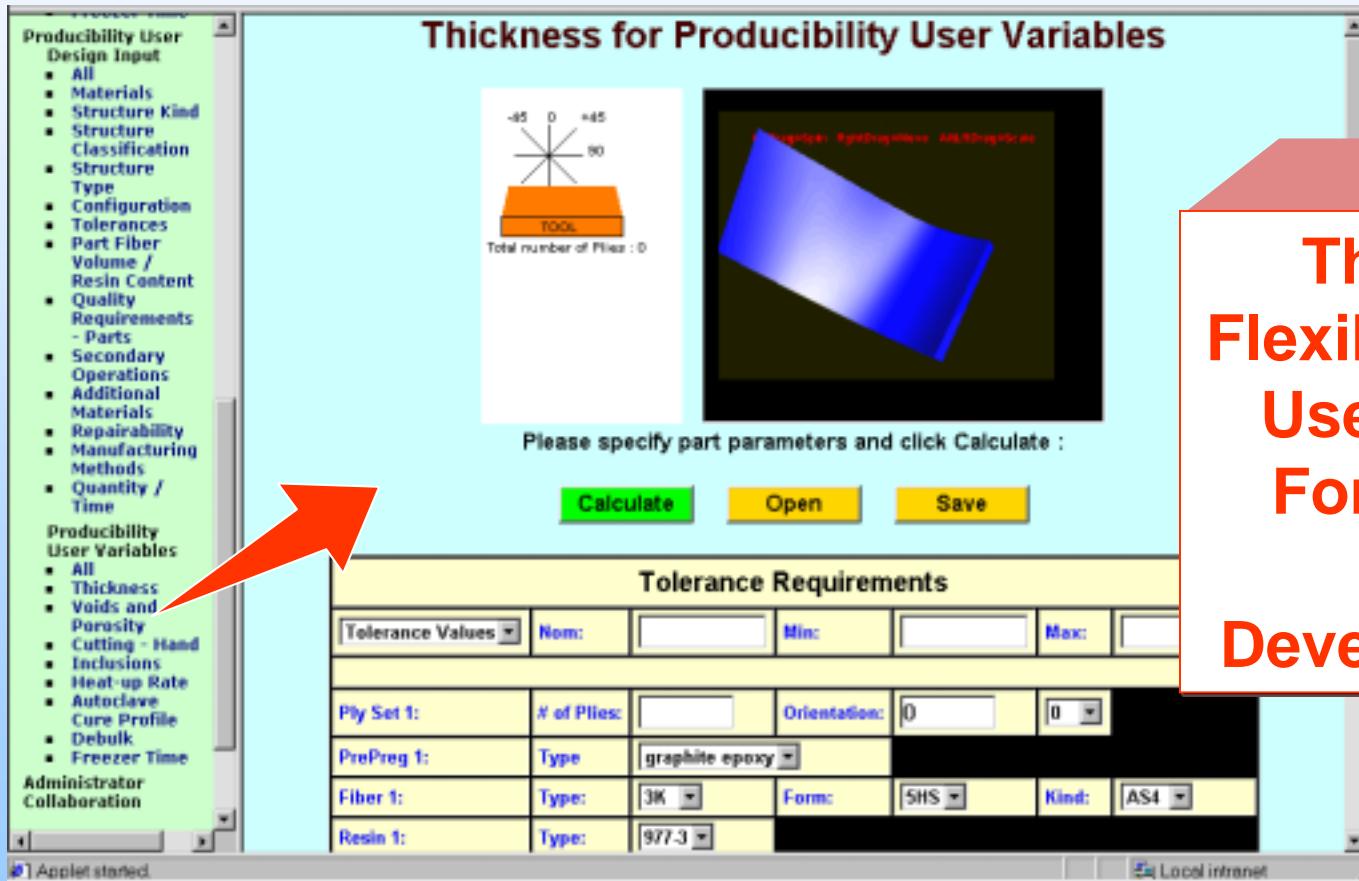
### Secondary Operations

tgest per ??? Specification

### Part Dimensions

# Producibility User

## Producibility – Quality: Thickness



Thickness for Producibility User Variables

Please specify part parameters and click Calculate :

Calculate   Open   Save

Tolerance Requirements					
Tolerance Values	Nom:	Min:	Max:		
Ply Set 1:	# of Plies:		Orientation:	0	0
PrePreg 1:	Type:	graphite epoxy			
Fiber 1:	Type:	3K	Form:	SHS	Kind: AS4
Resin 1:	Type:	977-3			

Administrator Collaboration

1 Application started.

The Module Is  
Flexible So Different  
Users Can Use It  
For Their Needs  
Later In a  
Development Cycle

# Producibility User Producibility – Quality: Thickness

Producibility User Design Input

- All
- Materials
- Structure Kind
- Structure Classification
- Structure Type
- Configuration
- Tolerances
- Part Fiber Volume / Resin Content
- Quality Requirements - Parts
- Secondary Operations
- Additional Materials
- Repairability
- Manufacturing Methods
- Quantity / Time

Producibility User Variables

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Administrator Collaboration

Please specify part parameters and click Calculate :

Calculate   Open   Save

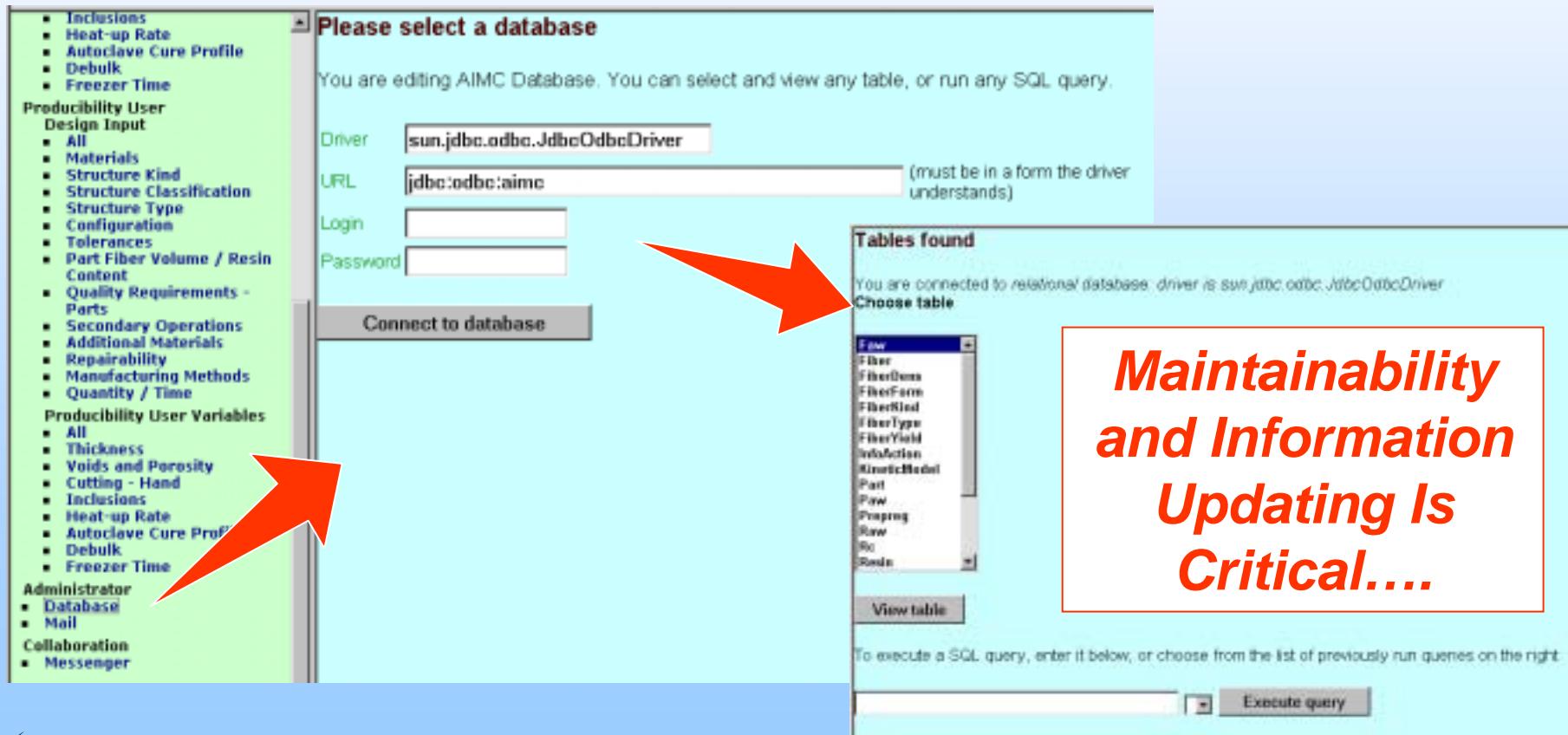
Thickness	Min	Max	Avg	Range
Part	0.157646	0.16918	0.163356	0.011534
per ply (set 1)	0.013137	0.014098	0.013613	0.000961
per ply (set 2)	0.013137	0.014098	0.013613	0.000961
per ply (set 3)	0.013137	0.014098	0.013613	0.000961
per ply (set 4)	0.013137	0.014098	0.013613	0.000961

Good: thickness variations within tolerance

Via Least Method

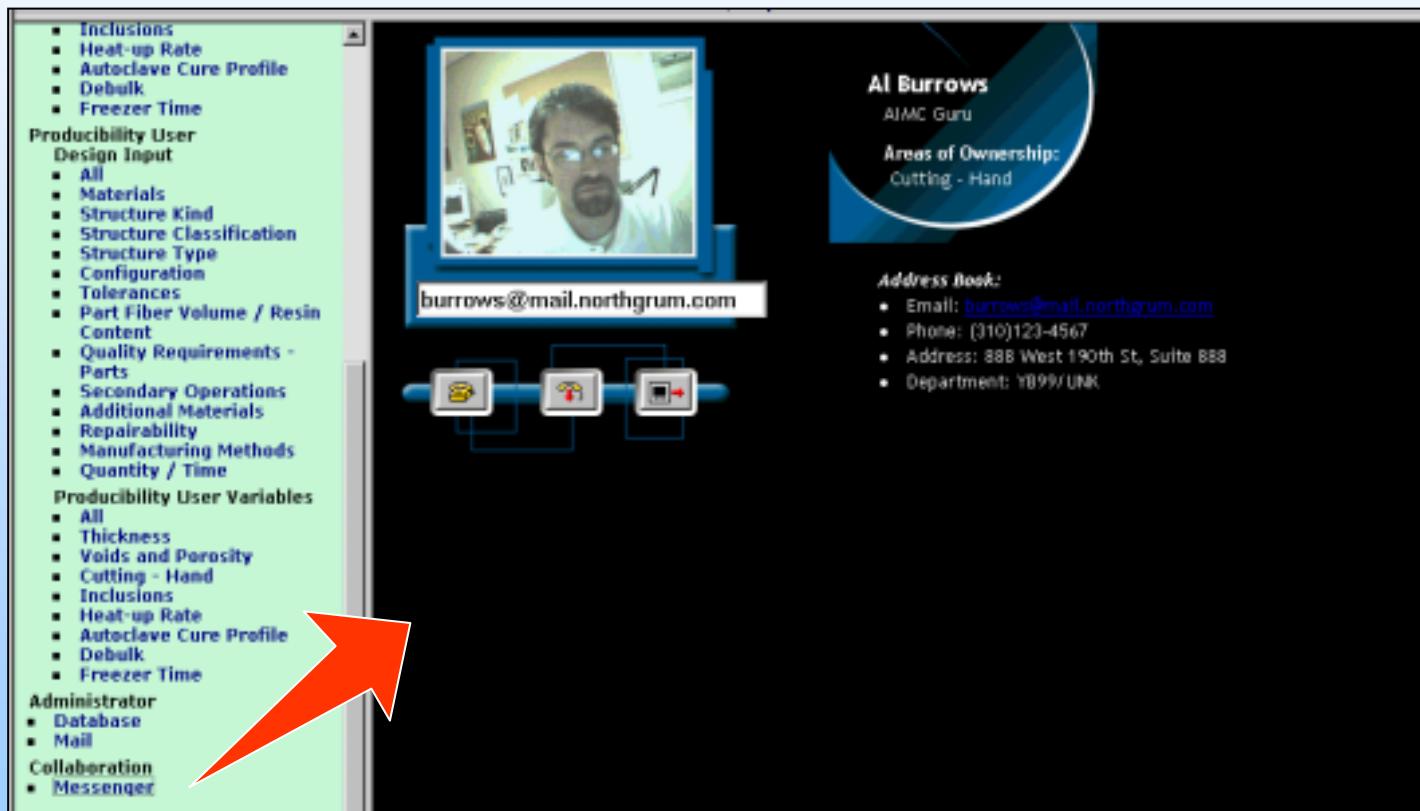
*Output According  
To Needs*

# Administrator User Data Base Management



The screenshot shows a database management application interface. On the left, a sidebar menu lists various categories such as Inclusions, Heat-up Rate, Autoclave Cure Profile, Debulk, Freezer Time, Productivity User, Design Input, Quality Requirements - Parts, Secondary Operations, Additional Materials, Repairability, Manufacturing Methods, Quantity / Time, Productivity User Variables, Administrator, and Collaboration. Two red arrows point from the 'Administrator' and 'Collaboration' items in the sidebar to the main interface area. The main area has a title 'Please select a database' and instructions: 'You are editing AIMC Database. You can select and view any table, or run any SQL query.' It includes fields for Driver (set to sun.jdbc.odbc.JdbcOdbcDriver), URL (jdbc:odbc:aimc), Login, and Password. A 'Connect to database' button is present. To the right, a 'Tables found' section displays a list of tables: Paw, Fiber, FiberItems, FiberForm, FiberHist, FiberType, FiberYield, Infraction, KineticModel, Part, Paw, Preproc, Raw, Re, Resin. Below this is a 'View table' button. At the bottom, there is a text input field for SQL queries and an 'Execute query' button. A large red arrow points from the 'Administrator' sidebar item to the main interface area. A red box on the right contains the text: **Maintainability  
and Information  
Updating Is  
Critical....**

# Collaboration User Messenger



The screenshot shows a software application window titled "Collaboration User Messenger". On the left, a sidebar lists various user categories and their sub-options:

- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Productibility User

- Design Input
  - All
  - Materials
  - Structure Kind
  - Structure Classification
  - Structure Type
  - Configuration
  - Tolerances
  - Part Fiber Volume / Resin Content
  - Quality Requirements - Parts
  - Secondary Operations
  - Additional Materials
  - Repairability
  - Manufacturing Methods
  - Quantity / Time

Productibility User Variables

- All
- Thickness
- Voids and Porosity
- Cutting - Hand
- Inclusions
- Heat-up Rate
- Autoclave Cure Profile
- Debulk
- Freezer Time

Administrator

- Database
- Mail

Collaboration

- Messenger

A large red arrow points from the bottom left towards the "Messenger" option in the sidebar.

In the center, there is a user profile for "Al Burrows" (AIMC Guru) with "Areas of Ownership: Cutting - Hand". Below the profile is an "Address Book" section with the following information:

- Email: [burrows@mail.northgrum.com](mailto:burrows@mail.northgrum.com)
- Phone: (310)123-4567
- Address: 888 West 190th St, Suite 888
- Department: YB99/UNK

# Summary

- ***Basic Effort Accomplishments:***
  - Design User Interface for Producibility
  - Producibility Quality Areas of Thickness and Voids
  - Producibility Operation/Processing Area of Cutting and Indirect Materials
  - Recommendations Based on Inputs and Lessons Learned
  - Integration of Producibility Module Multiple Component Pieces
  - Integration of Producibility Module with other Modules



## Future Plans

- Populate Module For Core Flat Panel Fabrication Producibility Analysis
- Populate Module For Panel With Ramp Feature Fabrication Producibility Analysis
- Populate Module For Flat Panel With Co-cured Hat Stiffener Fabrication Producibility Analysis
- Populate Module To Perform Producibility Analysis With Combination Of Co-Cured Hat Stiffened Panels And Ramps To Support The Compelling Demonstration

## A Feature Based Producibility Assessment Through Parameterized Process Modeling

- Motivation

- Augment current heuristic approach for cure cycle design with a physics based prediction methodology
- Make a high-end **analysis** tool (AIM-C Processing Module) available for **design** through RDCS
- Demonstrate integration between the web based front-end of Producibility and RDCS

- Integration approach

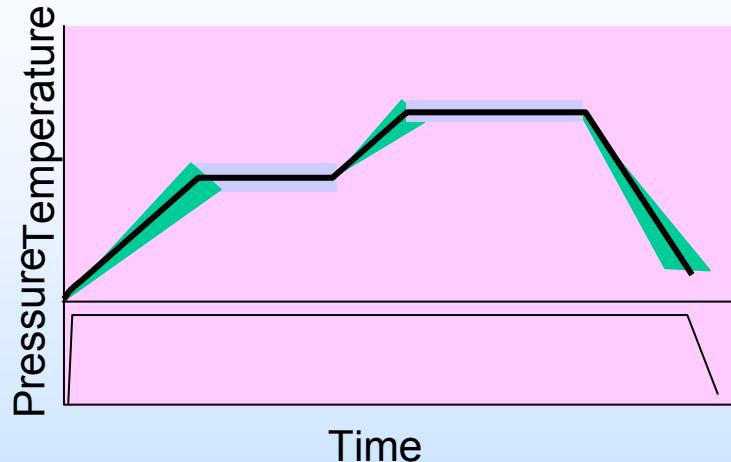
- Parameterize AIM-C Processing Module input/output
- AIM-C Processing Module embedded in a Math model
- Web based GUI for a design process (genetic optimization)
- Producibility module creates RDCS batch file
- Pilot version of invoking RDCS on the designer's desktop
- Design exploration to find cure cycle that meets heat-up requirements

- Accomplishments

- Designed feasible curing cycle that met heat-up requirements
- Identified fabrication processes that are likely to result in defective parts

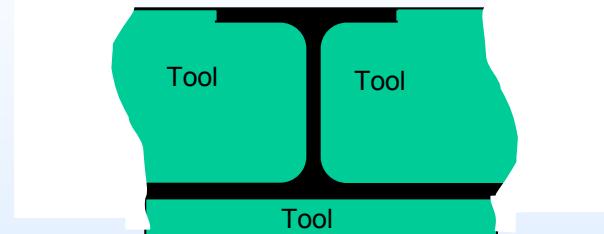
## Use Scenario and Problem Statement

### Composite System Cure Requirements



- Resin chemistry requirements
- In-cure and residual stresses
- Minimum and maximum rates
- Minimum and maximum hold times
- Intermediate temperature holds

### Design and Tooling Requirements



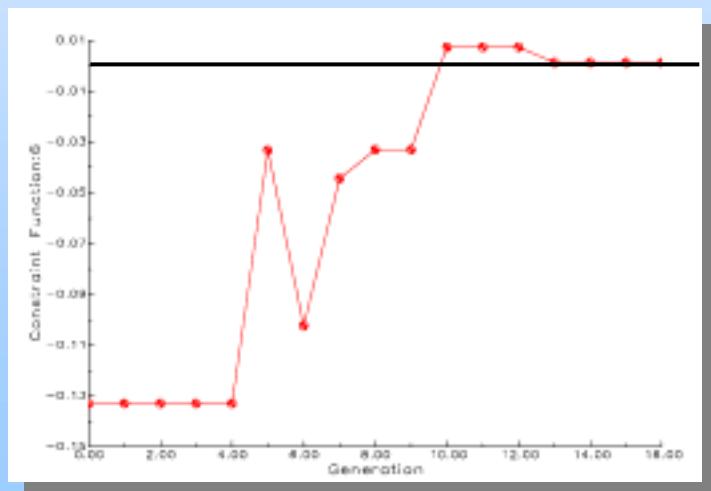
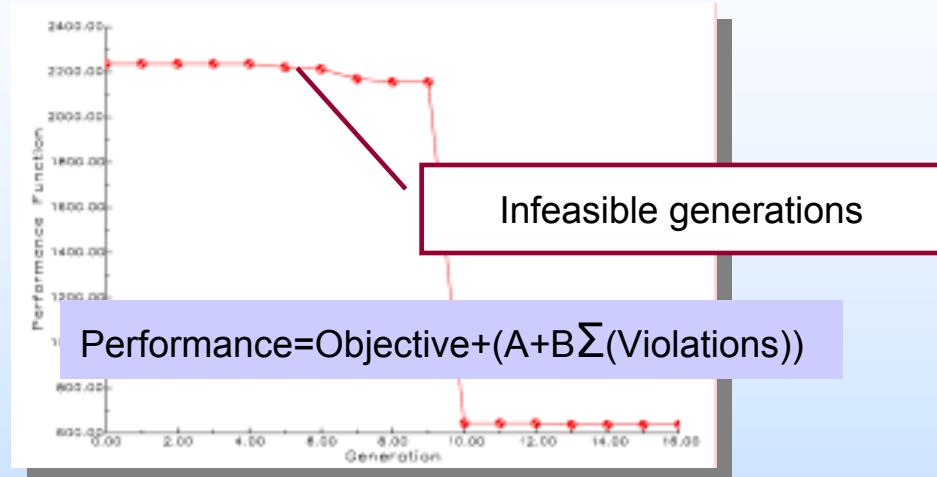
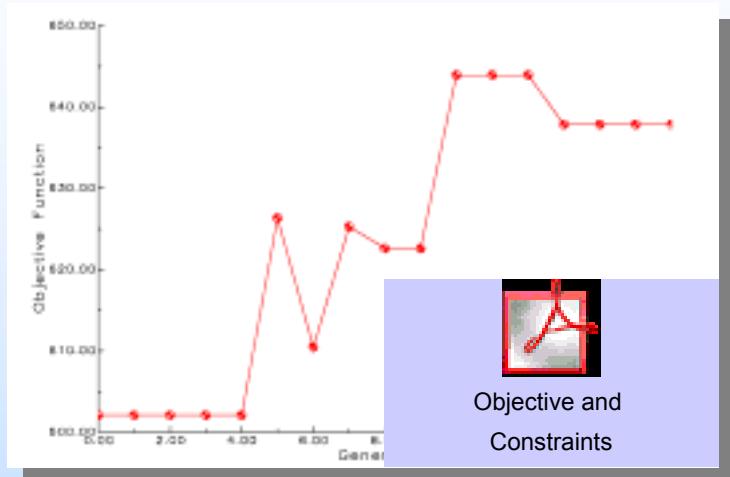
Thermally massive tooling, inserts  
Co-cure Tail, Ti Wing Root



Thick and Thin Sections  
Keel beams, Attachment points  
Combinations of Above

Evaluate Design Driven Requirements Relative to Material and Processing Requirements for Heat-up Rate and Exotherm Producibility Issues

# Representative Results: Thin part, thick aluminum tool



## Important constraints

- 4 - Minimum part heat-up rate at ramp 2
- 5 - Maximum time at final cure temperature
- 6 - Minimum time at final cure temperature
- 7 - Maximum acceptable heat-up gradient

Resource needs: ~ 550 evaluations

3 hrs wall clock time (100 workstations)



## Conclusions

- Demonstrated Integrated Producibility-Processing-RDCS Design Tool
- Tool was used to search for feasible heat-up cure cycles
- Feasible designs were not found in all cases
  - Insight into the process
  - Options: change tooling material or relax constraints
  - This is precisely what the AIM-C facilities are intended for:

Identify and solve design/producibility problems early to avoid cost and schedule overruns

# AIM-C Reduces Time and Cost of Insertion by Understanding the Actual Manufacturing and Structural Analysis of Real Applications

